ATTACHMENT TO SKYTEL COMMENTS ON PROGENY TEST REPORT

Review of the “WAPS” and “Part 15 Test Report”

Nishith D. Tripathi

Progeny has submitted a test report along with the description of their Wide Area Positioning system (WAPS) to meet the FCC requirements. This review report summarizes the findings based on the analysis of the Progeny report. *There are several shortcomings in the WAPS description.*

- While a test configuration is descried, description of the network configuration that yields the claimed location accuracy is absent.
- Impact of fundamental WAPS design parameters on the performance of Part 15 devices is not analyzed.
- The performance of the WAPS is not accompanied by any quantitative performance metrics and measurements.
- Impact of Part 15 devices on the WAPS performance is not evaluated.
- While the WAPS is described at a high-level, such description is inadequate to judge the efficiency of the WAPS operations.
- Since the WAPS inherently relies upon a non-WAPS network such as a cellular or WiFi (Wireless Fidelity) network to accomplish its goals, interworking of proprietary WAPS with these networks becomes quite important.
- However, feasibility study and operational proof of such interworking are missing.
- Discussion of the Quality of Service (QoS) considerations for the proprietary WAPS solution in contrast to the QoS-aware standardized solutions already specified in LTE (Long term Evolution) is absent.

The test report misses several key areas as well.

- Usability of the reported test results as a proof for compliance to the FCC rules is quite limited due to inherent lack of co-channel interference (CCI) for most test devices.
- Co-operative testing is not carrier out.
- Furthermore, single-device testing is done instead of multi-device testing, resulting in a test environment that is not representative of real-world scenarios where multiple Part 15 devices operate in a given area.
- Only stationary testing is done; vehicular testing is skipped altogether.

- Critical quantitative performance metrics and associated measurements for the WAPS and Part 15 devices are not provided.
- While the impact of the WAPS Interference on audio quality for Part 15 devices is correctly observed in specific cases, such observation is incorrectly interpreted, leading to an incorrect conclusion.
- Poor choice of the test devices has caused improper classification of typical and atypical part 15 device operations.
- The test results show that the performance metric for Part 15 data devices is unreliable.
- The WAPS is intended to provide superior performance where GPS-based solutions are insufficient (e.g., in dense-urban areas). However, adequate testing in such areas is not really done.
- The analysis of the test results shows that conclusions of the tests are too optimistic about the impact of the WAPS interference on Part 15 devices.

In summary, the Progeny report fails to prove that the WAPS would not cause unacceptable levels of interference to Part 15 devices.

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About the Author

Dr. Nishith Tripathi is a principal consultant at Award Solutions, a provider of technical consulting and specialized technical training for wireless communications. Dr. Tripathi's students include senior personnel from companies throughout the wireless industry as well as other wireless engineering instructors. Dr. Tripathi specializes in a variety of technologies, including IS-95, CDMA2000, 1xEV-DO, GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, HSPA+, WiMAX, and LTE. He received his doctorate in Electrical and Computer Engineering from Virginia Tech, and he has held several strategic positions in the wireless arena. As Senior Engineer for Nortel Networks, Dr. Tripathi gained direct hands-on experience analyzing and optimizing the performance of CDMA networks, in such areas as capacity, handoff and power control algorithms, supplemental channel management algorithms, and switch antenna diversity. As a Senior Systems Engineer and Product Manager for Huawei Technologies, he worked on the infrastructure design and optimization of CDMA2000, 1xEV-DO, and UMTS radio networks. Dr. Tripathi is the co-author of *Radio Resource Management* (2001) and *Cellular Communications: A Comprehensive and Practical Guide* (forthcoming) with Professor Reed. Dr. Tripathi has also contributed chapters to the following books: "Net Neutrality: Contributions to the Debate" (Edited by Jorge Perez Martinez, 2011) and "Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications" (Edited by Peter Stavroulakis, Springer, April 2004). Dr. Tripathi's complete vita is attached.

1. REVIEW OF "WAPS: NETWORK DESCRIPTION"

The Progeny WAPS network and the test report are described in the 84-page pdf file [1]. The page numbers referred to in this review paper correspond to the page numbers in the pdf file.

While a test configuration is described, description of the network configuration that yields the claimed location accuracy is absent. It is mentioned on Page 24 that "A total of 17 devices, 12 consumer devices and 5 commercial devices were selected for use in testing in the presence of an operational WAPS system." However, it is unclear if this "operational system" is the same system with a certain number of beacon transmitters at specific locations that yielded the claimed performance accuracy or this test system is a simplified configuration. The deployment configuration has a direct impact on the accuracy of the location estimates and the interference caused to Part 15 receivers. If WAPS beacon signals are too strong, the accuracy of the location estimates would improve but the interference caused to Part 15 receivers would be high. In contrast, if the WAPS beacon signals are weak, they will cause less interference to Part 15 receivers but will lead to poor Multilateration Location and Monitoring Service (M-LMS) performance.

The test results should include the achieved location accuracy due to the tradeoff between the density of the beacon transmitters and the interference caused to part 15 devices. Furthermore, M-LMS intends to perform well where a Global Positioning System (GPS)-based system fails (e.g., in a dense-urban environment). Density of both WAPS beacon transmitters and Part 15 devices can be expected to be higher in a dense-urban environment. While building penetration loss could certainly mitigate interference to a certain degree, only test measurements can truly quantify the impact of the network configuration. Such test measurements are absent in [1].
Figure 4 on Page 41 shows the geometric dilution of precision analysis (GDOP) coverage for the WAPS test network in Santa Clara County. However, it is unclear the location estimate accuracy achieved for such GDOP coverage. It is also not mentioned how the GDOP map was created; whether it was based on real M-LMS receiver measurements or theoretical signal-strength based propagation tools. Relevant measurements such as received signal strengths and beacon (or pilot) (E_c/I_0))[1] for M-LMS should have been specified.

The WAPS is intended to provide superior performance where GPS-based solutions are insufficient (e.g., in dense-urban areas). However, adequate testing in such areas is not really done. Furthermore, achieved location accuracy and associated performance metrics and measurements are not specified.

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[1] Beacon (or pilot) (E_c/I_0) is the ratio of the energy per chip and the total power spectral density and can be calculated as the ratio of the received pilot or beacon channel power and the total received power including the received power of all the channels and thermal noise.

Impact of fundamental WAPS design parameters on the performance of Part 15 devices is not analyzed. The WAPS network transmits two beacons that last for 100 ms each (with a total of 200 ms) every second. While the duty cycle is 20%, the continuous transmission of beacons for 100 ms is problematic for both speech and data whenever strong WASP signals and the Part 15 device signals are co-channel. It is well-known that the physical layer cannot overcome a long burst of errors. Channel coding and interleaving implemented at the physical layer typically work well in case of scattered errors and a short burst of consecutive errors. Since the beacon is present for a long time, the probability of entire speech and data packets being lost is very high. The proof of the inability of the physical layer of several Part 15 devices to overcome long bursts of errors introduced by the WAPS interference is evident in the "beep" sound heard in numerous instances during the tests. If the Part 15 receiver were able to work well in the presence of the WAPS interference, such "beep" sound would not be audible at all.

The claimed performance of the WAPS is not accompanied by any quantitative performance metrics and measurements. Page 6 says that "The NextNav solution is highly accurate. In initial testing across approximately 240 square kilometers in Santa Clara County, NextNav has achieved accuracy of better than 25 meters, 67 percent of the time. NextNav has also demonstrated height accuracy to within 1 to 2 meters, which provides a distinct benefit in multi-level structures." However, no performance metrics and measurements such as signal strengths, pilot (E_c/I_0), and signal-to-interference ratio are included in support of such claimed performance. The beacon transmitter locations to achieve such accuracy are not specified. Impact of the Part 15 transmitters on the accuracy of the location estimate devices on the WAPS performance is not evaluated.

Page 14 claims that "Further, NextNav's technology is the only wide area solution that precisely addresses the 'Z' axis problem providing meter level accuracy." This author notes that Mr. Warren Havens will be submitting concurrently with this Report, information addressing this claim, and in addition, this author may address this in further comments in this proceeding.

While the WAPS is described at a high-level, such description is inadequate to judge the efficiency of the WAPS operations. The WASP network utilizes a 50 bits per second (bps) data rate and the duty cycle of 20%. Adequacy of these design parameters for the claimed accuracy of the M-LMS performance is not justified. The WAPS description does not explicitly mention if all the beacon transmitters are synchronous or asynchronous.

The use of a low data rate yields a large link budget due to a huge processing gain but would lead to longer time to estimate the location because a single message carrying the beacon transmitter's location and local barometric pressure would need many 100 ms slots. The use of a low data rate can pose a significant challenge to the location estimation algorithm in the M-LMS receiver because of the mobility of the device. Retrieving the location and pressure from a message would take a long time and would jeopardize the use of this location information especially when the user device is moving on a highway. The time required for the location estimation is not quantified and the relevant measurements are not specified.

The WAPS network inherently relies upon a non-WAPS network such as a cellular or WiFi (Wireless Fidelity) network for the M-LMS receiver to convey its location and height to the network, interworking of proprietary WAPS with these networks becomes quite important. However, *feasibility study and an operational proof of WAPS-cellular or WAPS-WiFi interworking are missing*. The design of the M-LMS receiver is skipped. The M-LMS device requires special hardware for Radio Frequency (RF) measurements and software for Secured User Plane (SUPL) and for interworking between M-LMS and cellular or WiFi.

Discussion of the Quality of Service (QoS) considerations for the proprietary WAPS solution in contrast to the QoS-aware standardized solutions already specified in LTE (Long term Evolution) is absent. It is mentioned on P13 that "NextNav is deploying its network to meet urgent public safety and commercial market needs. Wireless E911, particularly from mobile handsets, has become a predominately indoor service, while many modes of mobile communication increasingly rely on location information to provide consumer value." However, the LTE standard, from Release 9 onwards, already supports such location service. Furthermore, LTE is expected to be a dominant cellular technology and the LTE solution is a standardized solution. In a typical case, where the cellular operator is unaware of the mobile device's proprietary way of implementing a location-based service, such service would be assigned a best-effort QoS class[2]. The operator's LTE standard-based method of providing E-911 (and other services) would be given a high-priority QoS class.

Quantitative location performance comparison among the Progeny WAPS and other location systems is missing. While the achievable performance of the WAPS is mentioned (although without any supporting information such as the network configuration and the M-LMS device specifications), a comprehensive performance comparison among the Progeny WAPS and the existing location systems is not carried out. Since the WAPS design parameters such as a very low data rate of 50 bps and a 100 ms timeslot carrying data every second appear to be inadequate (in the absence of any supporting proof of performance), such performance comparison becomes quite important. If the achieved accuracy is low (especially in the vehicular environment), the complexity of the M-LMS device and the reliance on non-M-LMS technologies to convey the device location to the network would not be attractive to the acceptance of the WAPS. Assisted-GPS techniques such as Network Real-Time-Kinematic (RTK) can have an enviable accuracy (on the order of centimeters!) [5]. Of course, a tradeoff between the location accuracy and the

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[2] Providing QoS-aware service requires cooperation and agreements between Progeny and the cellular provider. When the cellular provider already has an LTE-based solution for location services, the cellular provider may not have any motivation to enter into agreements with Progeny, especially considering the interoperability test requirements and the increased complexity of the mobile devices.

cost would be needed while choosing a specific location technique for the intended purpose. Inertial Navigation Systems (INS) can be exploited in the areas where a pure GPS-based location solution is inadequate [6].

While the WAPS does not have the return link or uplink, there is no mention of any "traffic" or "data" channel that will allow one-way communication to the M-LMS devices. The only data rate channel mentioned is a 50 kbps channel that carries information to facilitate location estimate at the M-LMS receiver. If there is any other use of this channel or if there is any other "data" channel, such information is missing and should be clarified. More specifically, all the physical layer channels defined in the WAPS should be clearly described.

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2. REVIEW OF "PART 15 TEST REPORT"

Various issues associated with the tests are briefly discussed below.

Usability of the reported test results as a proof for compliance to the FCC rules is quite limited due to inherent lack of co-channel interference (CCI) for most test devices.

The Part 15 test device selection method has led to many deices not operating on the same frequency spectrum as the WAPS beacons. While it is a good idea to quantify the impact of Adjacent Channel Interference (ACI), CCI is much more relevant to the testing under consideration and truly tests the amount of potential WAPS interference. Since only few of the selected test devices really operate on the frequency spectrum used by the WAPS beacons, the occurrence of the WAPS interference appears to be less frequent. Two WAPS beacons occupy 919.75-921.75 MHz and 925.25-927.25 MHz spectrum. Four test devices out of 17 test devices operate around 919.75-921.75 MHz. These four devices used analog FM (Frequency Modulation) technique and operated in the ranges: (i) 925.2 to 926.2 MHz, (ii) 925.610677 to 927.698745 MHz, (iii) 925.8 to 927.4 MHz, and (iv) 925.3 to 927.2 20 MHz. One device operated from 909.524 MHz to 919.764 MHz, which is effectively outside the WAPS ranges. 7 out of 17 test devices (device number 11 to 18 with 13 unused) had the operating ranges much greater than 2 MHz WAPS bandwidth, minimizing the likelihood of interference in the test environment. In the real-world scenario, existence of other LMS systems and other Part 15 devices and systems in the 902-928 MHz frequency band would have resulted in much more frequent WASP interference than that conveyed by the test results.

The tests do not meet the FCC requirements related to the purpose of the tests. The purpose and essential requirements of the Progeny tests are set forth by the FCC in the Order granting to Progeny several rule waivers [2], as follows: "…Included in these rules is the obligation, set forth in Section 90.353(d), that Progeny demonstrate through actual field tests that its M-LMS system will not cause unacceptable levels of interference to Part 15 devices [3]. As the Commission noted, the purpose of the testing condition "is to insure that multilateration LMS licensees, when designing and constructing their systems, take into consideration a goal of minimizing interference to existing deployments or systems of Part 15 devices in their area, and to verify through cooperative testing that this goal has been served." [4]. Testing was done by selecting a set of standalone Part 15 devices. There are several Part 15 systems already in existence in California. For example, Pacific gas and Electric in Silver Springs is using a Part 15 system for meter readings. Testing should have involved such Part 15 systems to accurately quantify the impact of WAPS interference on the operation and performance of the Part 15 system and the impact of the Part 15 system on the accuracy of the location estimate of the M-LMS receiver.

Single-device testing was done instead of multi-device testing, resulting in a test environment that is not representative of real-world scenarios where multiple Part 15 devices operate in a *given area*. Since the testing was carried out using a single active Part 15 test device, it was much easier for the device to find an unoccupied channel, avoiding the Part 15 interference and WAPS interference. However, in practice, there may be a multiple Part 15 devices in a given area. The likelihood of WAPS interference increases significantly depending upon the number of Part 15 devices, the operational frequency ranges of Part 15 devices, and existence of Part 15 systems. It is mentioned on Page 36 that "It was therefore expected that the concentration of Part 15 uses in the vicinity of the test location would be quite high." However, the existence of other Part 15 devices cannot be assumed; only the testing with a cluster of Part 15 test devices can truly guarantee the testing in a multi-device real-world environment.

Only stationary testing was done; vehicular testing was skipped altogether. The details of the test locations and test procedures given in [1] do not point to any vehicular tests. The applicability of the test results is thus further restricted to the stationary location service only.

Critical quantitative performance metrics and associated measurements for the WAPS and Part 15 devices are not provided. Example measurements include received signal strength, signal to interference ratio (SIR), and pilot (E_c/I_0). Voice-specific and data-centric performance metrics are frame or block error rate and throughput.
While it is mentioned on Page 36 that "Several criteria were considered in selecting specific test locations, the most important of those being in-building coverage from at least four WAPS beacons with sufficient angular diversity to achieve the targeted system accuracy.", no measurements and performance metrics are specified in support of this statement.

A good observation is made on Page 52: "In certain instances when the beacons were operational, an audible "shhh" or "beep" pulse was detected. Although the pulse could vary in sound and intensity, it had a regular period of one second." Such observation implies that the level of the WAPS interference is high enough to cause the failure of the physical layer operation of the Part 15 receiver. Specification of the associated measurements and performance metrics for all the strong beacons and the Part 15 transmitter is missing; such specification would have provided valuable insight in correlating the measurements with the observed "beep" pulse. The mention of the achieved M-LMS location estimate accuracy is also important to correlate with the measurements. For example, if the location accuracy is low but the interference is high, the interference would be even higher when the M-LMS is operated at the target level of location accuracy.

While Page 63 states that "In nearly all cases in which a WAPS beacon signal was detected, the signal artifact of only one WAPS transmitter could be identified on the resulting audio sample. The cases in which two beacons were detected were rare and in no test case were more than two beacon signals detected," it is unclear how determination of the detection of one versus more than one beacon was made. The type of the equipment used to make such determination should be specified, because of varying capabilities of the equipments (e.g., a spectrum analyzer vs. a Pseudo-Noise (PN) scanner). Furthermore, measurements should have been specified for the relevant number of beacons (e.g., strongest four to five beacons with their identities, received signal strengths, and (E_c/I_0)s).

While the impact of the WAPS Interference on audio quality for Part 15 devices is correctly observed in specific cases, such observation is incorrectly interpreted, leading to an incorrect conclusion on the impact of the WAPS interference on audio quality. Page 3 mentions that "…resulting in a brief "shh" or "beep" sound at one second intervals…the Part 15 device continued to operate, sending and receiving desired signals, and the ability to recognize speech was unchanged by the beacon signal." However, a beep every single second during the conversation would be annoying to most (if not all!) people. Acceptable speech quality corresponds to 1% to 3% error rate, meaning 3 speech frames (each with a 20 ms time interval) have errors. If these errors in consecutive speech frames (which would be the case when the WAPS interference is high due to a burst of a beacon signal), they correspond to a 60 ms time window out of 2000 ms time period. A 100 ms long beacon duration could cause a loss of 5 speech frames, leading to 5% error rate. This error rate would be in addition to the inherent error rate achievable by the Part 15 system design. It is, therefore, not surprising that a "beep" sound reflective of degraded and undesirable voice quality was heard in the presence of high WAPS interference.

Page 3 further states that "Further, moving the Part 15 transmitter and receiver closer together diminished or eliminated the M-LMS signal artifact." However, it may not always be practical to change the distance between the Part 15 transmitter and the Part 15 receiver.

Poor choice of the test devices has caused improper classification of typical and atypical part 15 device operations. While an attempt is made in [1] to classify a given situation into typical or atypical operation, such attempt is a function of numerous factors. For example, Page 23 mentions this about "atypical" operating conditions: "Therefore, a second test segment was employed in which Part 15 consumer devices were tested in atypical operating conditions. The test environment for the atypical conditions was the same as in the typical test environment. In the atypical conditions, however, Part 15 devices always operated on the same frequency with a WAPS beacon." However, the devices that have operating frequency ranges within the WAPS frequency range would indeed experience so-call "atypical" conditions; in fact, four out of seventeen test devices are like that. "Atypical" conditions for some devices and circumstances can be "typical" for other devices and circumstances.

The performance evaluation under so-called "atypical conditions" accurately quantifies the impact of co-channel interference on the Part 15 receiver. Several factors would lead to more frequent occurrence of the "atypical conditions", making them "typical conditions." For example, as mentioned above, a Part 15 device with the operating frequency range inside the WASP frequency band would always experience "atypical" conditions. A Part 15 device with a limited frequency range could also experience "atypical" conditions in the presence of other Part 15 devices and systems and other non-WAPS LMS systems. Strong WAPS beacons (required to achieve a target level of location accuracy) could also increase the likelihood of a device experiencing “atypical” conditions.

As mentioned on Page 61, 27 instances out of 117 test instances experienced the audio quality degradation in the form of “beep” sounds for “atypical” conditions. Since “atypical” conditions are quite “typical” in many cases as discussed above, the WAPS interference cannot be considered to be negligible.

While Page 59 states that “…except for the wireless pendent, which could not operate on another channel. Note that the wireless pendant was able to detect the WAPS signal only at two locations where the WAPS beacon was relatively close, as indicated in Table 11.”, one detected beacon was 0.2 miles away and another detected beacon was 0.8 miles away. These distances are realistic distances where Part 15 devices can be found.

The test results show that the performance metric for Part 15 data devices is unreliable. Table 11 on Page 65 clearly shows that the range results not reliable and that range as a performance metric is not useful. For example, in some cases, the range increases when the WAPS network is activated.

While page 3 states that “SMC found that the M-LMS transmission had no material impact on their operation. When the M-LMS signal was present, these Part 15 devices continued to transmit the desired data over distances consistent with what could otherwise be achieved when an M-LMS signal was not present.” Unreliability of the range cannot corroborate these statements. Supporting evidence in the form of measurements and other performance metrics is needed.

The extremely narrow scope of the tests prevents the applicability of their results to a nationwide Progeny network. The limited set of selected Part 15 devices, the lack of the participation from and existence of Part 15 systems in the tests, lack of consideration of the amount of peak traffic generated by individual Part 15 devices and Part 15 systems, and the limited number of test cases (e.g., focus on stationary environment only) are example factors that restrict the applicability of the test results.

REFERENCES

[1] Progeny LMS, LLC, "Demonstration of Compliance with Section 90.353(d) of the Commission's Rules," WT Docket No. 11-49, January 27, 2012.

[2] FCC, DA 11-2036 at 25.

[3] 47 C.F.R. § 90.353(d).

[4] LMS MO&O, 12 FCC Rcd at 13968 ¶ 69.

[5] Lambert Wanninger, "Introduction to Network RTK," 16 June 2008, http://www.wasoft.de/e/iagwg451/intro/introduction.html.

[6] See, e.g., the Comments of Warren Havens, for companies he represents, submitted to the FCC along with this Report by this author, including the two Exhibits authored by professors at the University of California, Berkeley. See also, Trusted Positioning, "Trusted Vehicle Navigator (T-VN)," http://www.trustedpositioning.com/TPI_products_tvn.html?gclid=CKCz_b-Y6a4CFahgTAodbiDi-Q.

AUTHOR VITA

Nishith D. Tripathi, Ph. D.
419 Stone Bridge Circle, Allen, TX 75013
Tel.: 214-477-3516 and E-mail: ntripathi123@att.net

AREAS OF EXPERTISE

LTE (E-UTRAN and EPC), LTE-Advanced, WiMAX, 1xEV-DO (Rev. 0 and Rev. A), UMTS R99, HSDPA, HSUPA, HSPA+, CDMA2000 1xRTT, IS-95, CDMA, OFDM, OFDMA, Advanced Antenna Technologies, IP-related Technologies, IMS

PUBLICATIONS

- Author of an upcoming **book** (with Jeffrey H. Reed), "Cellular Communications: A Comprehensive and Practical Guide," ***Accepted for Publication by IEEE/Wiley***, 2012. (**Book Contents**: Introduction to Cellular Communications, Elements of a Digital Communication System, Radio Propagation, IP Fundamentals, GSM, GPRS, EDGE, IS-95, CDMA2000 1xRTT, R99 UMTS/WCDMA, 1xEV-DO Rev. 0, HSDPA, 1xEV-DO Rev. A, HSUPA, HSPA+, IMS, Emerging 4G Technologies)
- Author of a **book** (with Jeffrey H. Reed and Hugh F. VanLandingham), "Radio Resource Management in Cellular Systems," Kluwer Academic Publishers, 2001.
- Contributor (With Jeffrey H. Reed) to the article, "Technical Challenges in Applying Network Neutrality Regulations to Wireless Systems," in the book titled "Net Neutrality: Contributions to the Debate," Edited by Jorge Perez Martinez, 2011.
- Author of one chapter in the book, "Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications," Editor- Peter Stavroulakis, Springer, April 2004.

EXPERIENCE

AWARD SOLUTIONS *March '04 to Present*

Principal Consultant

- Successfully launched a new program to ensure and develop SME (Subject Matter Expert) expertise in the areas of LTE RAN and Ethernet-based Backhaul. Developed processes and plans to facilitate SME certification. Devised expertise development plans, on-line tests, and defense tests. Directed the oral defense meetings for the final stage of SME certification.
- Managed and led SMEs for following course development projects: LTE Bootcamp-Phase II (**Topics**: End-to-end Data Sessions in LTE-EPC, PCC: QoS and Charging Architecture for LTE, Voice over LTE (VoLTE) using IMS, Voice services using CSFB and SRVCC, LTE and eHRPD Interworking, LTE and GSM/UMTS interworking, and LTE-Advanced), and LTE Radio Network Planning and Design.
- Mentored SMEs to prepare them to teach technologies such as LTE, WiMAX, OFDM, and Advanced Antennas.
- Developed courses on LTE-Advanced and TD-LTE.
- Developed two sessions, TD-LTE and Self Organizing Network (SON), as part of LTE Bootcamp- Phase II for an infrastructure vendor.
- Enhanced the LTE Radio Network Planning and Design course to reflect configurations of commercial deployments using LTE log-files and to adhere to customer-specific RF design guidelines.
- Continued to teach a variety of LTE and HSPA+ courses (e.g., VoIP, IMS, and IPv6 for LTE and HSPA+ Signaling) at new and existing clients.
- Delivered several web-based sessions of LTE Bootcamp- Phase II.

Lead SME

- Taught *first-time offerings* of courses at various clients to acquire new training business.
- Managed and guided SMEs for timely and quality-controlled completion of following course development projects: LTE/1xEV-DO Interworking, EPC Overview, HSPA+ Overview, Fundamentals of RF Engineering, IP Convergence Overview, and Advanced Antenna Techniques.
- Devised and implemented strategies to maximize the quality of project deliverables and to accelerate the completion of the deliverables.

SME- Course Development

- Developed an in-depth LTE Bootcamp Series for an infrastructure vendor (**Topics**: EPS Network Architecture, OFDMA/SC-FDMA, Radio Channels, System Acquisition & Call Setup, DL & UL Traffic Operations, Handover, and Antenna Techniques).
- Developed numerous instructor-led and web-based training courses by working in a team environment (**Examples**: Interworking of LTE with 1xEV-DO & 1xRTT, LTE Air Interface, WiMAX Essentials, WiMAX Network Planning, UMB, 1xEV-DO, HSUPA, Multiple Antenna Techniques, and IP Convergence).
- **Example Course Contents**: Network architecture, air interface features, DL & UL data transmission, call setup, handover/handoff, resource management, and interworking.
- Designed outlines for several new courses.

Senior Consultant- Training

- Taught *in-person* and *web-based* (via WebEx and LiveMeeting) courses at major chip-set manufacturers, infrastructure & device vendors, service operators, and test-tool vendors.
- Delivered an in-depth LTE bootcamp multiple times for a major LTE infrastructure vendor.
- **Area Expertise**: LTE Radio Network Planning & Design (including Certification), Interworking of LTE with (1xEV-DO, 1xRTT, UMTS, and GERAN), LTE Protocols & Signaling, LTE Air Interface, WiMAX Networks and Signaling, 1xEV-DO Optimization, 1xEV-DO Rev. 0 and Rev. A, IP Fundamentals, HSDPA/HSUPA/HSPA+, UMTS R4/R5 Core Networks, UMTS Network Planning and Design
- Strived to make the training experience full of *relevant* knowledge and to maximize the value of training to students.

VIRGINIA TECH *January'10 to Present*
Adjunct Professor

- Co-taught the cellular communications class.
- Developed and presented the lecture material.
- Designed and graded quizzes.

HUAWEI TECHNOLOGIES *October '01 to March '04*
Product Manager and Senior Systems Engineer

- Worked with engineers to resolve numerous **field trial issues** for **CDMA2000** systems.
- Defined test procedures for various features to evaluate performance of the CDMA2000 product.
- Designed advanced RL MAC and Power Control algorithms for a 1xEV-DO System.
- Designed various high-performance radio resource management (RRM) algorithms for the **CDMA2000** base station and base station controller. Major designed features include adaptive forward link and reverse link call admission control algorithms, dynamic F-SCH rate and burst duration assignment algorithms, R-SCH rate assignment algorithm, F-SCH burst extension and termination mechanisms, schedulers, forward link and reverse link overload detection and control

algorithms, SCH soft handoff algorithm, F-SCH power control parameter assignment mechanism, adaptive radio configuration assignment algorithm, load balancing algorithm, and cell-breathing algorithm.

- Worked on the design of an RRM simulator to evaluate the performance of call admission control, load control, and scheduling algorithms for a **CDMA2000** system.
- Designed system level and network level simulators to evaluate the capacity gain of the smart antenna-based **UMTS** systems employing multiple beams.
- Reviewed **UMTS** RRM design and proposed enhancements related to call admission control, cell breathing, load balancing, soft capacity control, potential user control, and AMR control.
- Educated engineers through presentations to facilitate development of the **1xEV-DO** product.
- Led a team of engineers to define a comprehensive **simulation tool-set** consisting of link level simulator, system level simulator, and network level simulator to evaluate performance of CDMA systems including **IS-95**, **IS-2000**, **1xEV-DO**, **1xEV-DV**, and **UMTS**.
- Managed a group of engineers, prepared project plans, and established efficient processes to meet the requirements of the **CDMA2000** BSC product line.

NORTEL NETWORKS *September '97 to September '01*
Senior Engineer

Radio Resource Management, July '99 to Sept. '01

- Developed a comprehensive RRM simulator that models data traffic and major features of the MAC layer and physical layer. Analyzed various aspects of the RRM for several test cases. The performance results such as capacity and throughput were used in educating the service providers on the RRM for IS-2000 systems.
- Proposed a generic call admission control algorithm and filed a patent with the U.S. Patent Office.

Management of Supplemental Channels, June '00 to Sept. '01

- Designed and analyzed supplemental channel management for enhanced data performance and filed a patent with the U.S. Patent Office.

Data Traffic Modeling, Jan. '99 to Sept. '01

- Prepared a common framework for data traffic models for analysis of systems carrying data (e.g., 1xRTT and UMTS). Types of analysis include RF capacity, end-to-end performance, and provisioning. The data models for telnet, WWW, ftp, e-mail, FAX, and WAP services are considered.

Multi-Carrier Traffic Allocation, June '99 to Sept. '01

- Provided MCTA capacity improvements (compared to non-MCTA systems) that proved to be identical to the ones observed during the field-testing. Developed a method to estimate the MCTA capacity using the field data. This method was used in estimating MCTA capacity gains by RF engineering teams.

SmartRate and Related Vocoder Designs (e.g., SMV), June '99 to Sept. '01

- Provided estimates of SmartRate capacity improvements that were found to be close to the observed capacity gains in the field tests.

CDMA Based Fixed Wireless Access Systems, Sept. '97 to Dec. '98

- **Capacity Estimates**. Determined the system capacity for a variety of configurations using an IS-95 based simulator. These configurations include different rates such as 9.6 kbps and 13 kbps, different deployment scenarios such as 2-tier embedded sector and border sector, and different diversity techniques such as switch antenna diversity and phase sweeping transmit diversity. These capacity estimates were used for various project bids. The simulator utilizes propagation channel models extracted from the actual field measurements.
- **Handoff and Power Control Algorithms**. Analyzed existing handoff and power control mechanisms for fixed wireless systems and proposed new approaches.

- **Bridge between the Simulator and a Deployed System**. Developed a procedure to estimate the loading level for the simulator so that the capacity estimate from the simulator is close to the achieved capacity in real systems.
- **Switch Antenna Diversity Schemes**. Proposed three algorithms to exploit mobile switch antenna diversity. These schemes provide a low-cost solution that significantly enhances RF capacity.

  Combined Overhead Power and Handoff Management. Proposed a method of combined management of overhead channel power and handoff to improve capacity.

Educator

- Made presentations on topics such as data modeling, fixed wireless systems, and AI tools.
- Taught "Introduction to Wireless" class at Nortel.
- Prepared tutorials on the standards such as 1xRTT, 1xEV-DO, and UMTS.

VIRGINIA TECH *January '93 to August '97*

Research/Teaching Assistant, Mobile & Portable Radio Research Group (MPRG), Electrical Engineering

- Developed adaptive intelligent handoff algorithms to preserve and enhance the capacity and the Quality of Service of cellular systems.
- Helped *develop* and *teach* a new wireless communications course **(DSP Implementation of Communication Systems**) as part of an **NSF** sponsored curriculum innovations program. Implemented different subsystems of a communication system (e.g., a digital transmitter, a carrier recovery system, a code synchronizer, and a symbol timing recovery system) using the **Texas Instruments** TMS320C30 DSP development system.
- Refined the class material for undergraduate and graduate signal processing classes.
- Investigated different aspects involved in dual-mode adaptive reconfigurable receivers as part of a project sponsored by **Texas Instruments**.

PATENTS/DRAFTS (AUTHOR/CO-AUTHOR)

- Enhanced Power Control Algorithms for CDMA-Based Fixed Wireless Systems, Patent Number 6,587,442, Filed Date: October 28, 1999.
- Method and apparatus for managing a CDMA supplemental channel, Patent Number 6,862,268, Filed Date: December 29, 2000.
- Dynamic Power Partitioning Based Radio Resource Management Algorithm, Patent Disclosure No.: 11942RR, Filed Date: August 23, 2000.
- Switch Antenna Diversity Techniques at the Terminal to Enhance Capacity of CDMA Systems, Patent Disclosure No. RR2544, Filed Date: June 19, 1998.
- Adaptive Radio Configuration Assignment for a CDMA System, October 2003.
- Multi-carrier Load Balancing for Mixed Voice and Data Services, October 2003.
- Methodology for Hierarchical and Selective Overload Control on Forward and Reverse Links in a CDMA System, October 2003.
- A New Predictive Multi-user Scheduling Scheme for CDMA Systems, November 2003.
- A New Method for Solving ACK Compression Problem by Generating TCK ACKs based on RLP ACKs on the Reverse Link, October 2003.

ACTIVITIES

Member of **IEEE**. Reviewed research papers for the *IEEE Transactions on Vehicular Technology*, *IEE Electronics Letters* and the *IEEE Control Systems Magazine*.

EDUCATION

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY **Blacksburg, VA**

Ph.D., Wireless Communications, August 1997, Overall GPA: 3.8/4.0

Dissertation: Generic adaptive handoff algorithms using fuzzy logic and neural networks

M.S., Electrical Engineering, November 1994, Overall GPA: 3.8/4.0

GUJARAT UNIVERSITY **Ahmedabad, India**
B.S., Electrical Engineering, September 1992
Graduated among the top 2% of the class.